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GPS Data Link for Test and Training

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ABSTRACT

The Global Positioning System (GPS) is an excellent potential source of time-space-position information (TSPI) for test and training ranges, since this information is available world-wide and can be used by both air and surface players. However, in contrast to ground-based multilateration systems, GPS-derived TSPI is obtained on the player; hence, a means of conveying these data to the range central processor must be provided.

In this report, the feasibility of using existing data communications systems to report GPS-derived player position, velocity, and time data, with and without additional player event data, was examined. Data requirements for representative range systems were estimated and matched with the capabilities of representative data links.

It was concluded that telemetry and the Joint Tactical Information Distribution Systems (JTIDS) are the most viable link alternatives to convey the GPS-derived data to the range central processor.

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1.0 INTRODUCTION

The Global Positioning System (GPS) is a satellite-based navigation aid, which will provide accurate position, velocity, and time information to users anywhere in the world. The space segment of GPS will consist of 18 satellites in six orbits; each satellite broadcasts a uniquely coded signal from which a GPS receiver (user segment) can extract the signal's transit time and the satellite's ephemeris. Reception of signals from four satellites permits the user to determine his position and to correct his clock to GPS system time. The Institute of Navigation's monograph on GPS[1] describes the system and some of its applications.

Although GPS was designed for navigation, it has some aspects that make it attractive as range instrumentation, since time and player position are universal requirements for tests and training exercises. First, because GPS will be world-wide, the range need not be tied to a specific piece of real estate; variety in training is thus much more feasible. Second, because GPS will be satellite-based, terrain masking problems for ground players are alleviated. Finally, since GPS will be an operational system, eventually most players will come to the range with GPS sets as part of their equipment, so that additional equipment to provide time-space-position information (TSPI) will not have to be carried. The primary difference between GPS and conventional multilateration systems is that GPS will provide TSPI to the player. A data link is therefore required to integrate GPS into the range system.

To explore the use of GPS in tests and training exercises, the Director Defense Test and Evaluation directed the formation of a tri-Service committee, with the Air Force as lead service, and directed MITRE to support the committee as needed. A contract was let by the Tri-Service Committee to The Analytical Sciences Corporation (TASC) to analyse range requirements, compare GPS and

alternatives, identify technical issues, develop costs, and provide an implementation plan.

MITRE's task in support of the committee was to describe alternatives for a data link between the range's central processor and the participating players. The approach taken was to describe the data requirements of representative multi-player range systems, and then match these requirements with the capacities of representative data links. This report gives the results of that investigation.

Section 2.0 discusses data link considerations and identifies the two most promising data links: telemetry and the Joint Tactical Information Distribution System (JTIDS). In Section 3.0, the quantities of data generated by representative range systems are estimated; in Sections 4.0 and 5.0, the corresponding telemetry and JTIDS capacitites are estimated. Section 6.0 presents conclusions.

Access to JTIDS for GPS-derived data on the fighter and attack aircraft now being introduced will be through the MIL-STD-1553 data bus; however, data from other aircraft systems will also be carried by the data bus and could be transmitted by the JTIDS terminal as well. The data bus thus provides a means for solving two problems associated with the use of operational aircraft in tests and instrumented training exercises: installation of sensors to generate data, and transfer of data from sensor to data link transmitter. Use of aircraft tactical systems to generate, transfer within the aircraft, and transmit data for use in training evaluations would decouple training from fixed sites, thus making it more readily available and more realistic. This "avionics-based training concept" is discussed in Appendix C.

2.0 DATA LINK CONSIDERATIONS

The area of specific interest in MITRE's task was the feasibility of using existing data communications systems to report GPS-derived player position data (with or without additional player event data) in tests and training exercises. Three types of data links were considered: the GPS translator, telemetry, and tactical data links. The multi-object tracking radar and similar radar based data links were not considered; while these systems might be suitable for air players, it seems unlikely that they could track surface players satisfactorily.

The GPS translator receives superimposed signals from satellites in its view, converts the composite signal to a different frequency, and retransmits the signal at that frequency to a receiving station. The receiving station contains a GPS set that extracts the position, velocity, and time data from the composite satellite signals. The translator is an attractive solution for missiles and target drones, since it is small, lightweight, and considerably cheaper than the full GPS set. Five players is about the practical limit, however, since unlike satellite signals, the translator signals cannot be overlapped due to noise limitations, and large frequency allocations are not readily available. Appendix A gives the calculations leading to this conclusion.

Telemetry is now used on ranges to obtain both player event and test item data. In principle, GPS-derived TSPI is just another block of data to be transmitted to the range central processor. Telemetry should be capable of satisfying the data transfer requirements for small range systems when GPS is used, but as the numbers of players increase, a capacity limit might be encountered. To investigate this possibility, estimates of data rates for range systems of different sizes were needed; these estimates are given in the next section, and the corresponding

corresponding telemetry bandwidths and data rates are given in Section 4.0.

Several tactical data links were considered: The Forward Area Alerting Radar (FAAR) data link,[2] the Single Channel Ground and Airborne Radio System (SINCGARS-V),[3,4] the AN/TRC-145 multichannel communication system,[5] and JTIDS. SINCGARS and the FAAR data link are not designed to connect many users to one central point (the range data link's function), and user access to the 12-channel TRC-145 is provided by wire connections to an entrance panel, not suitable for moving range players. JTIDS offers promise, but would be practical only if range data can share the link with players' operational data. Like telemetry, JTIDS might encounter a capacity limit as the numbers of players increase. Use of JTIDS as a data link is discussed in Section 5.0, using the data estimates of Section 3.0.

3.0 DATA RATES FOR REPRESENTATIVE RANGE SYSTEMS

Data rates for representative range systems were estimated by postulating generic messages for the types of players participating, and then generating these messages at the rates specified by the systems for each type of player. The generic messages were postulated after studying the types of data called for in a number of range systems and large-scale exercise specifications,[(6-24)] substituting GPS-derived position, velocity, and time for the multilateration schemes employed. Player messages and overall data rates for the representative range systems are discussed below.

Five range systems were used: The Tactical Aircrew Combat Training System (TACTS), the Extended Area Test System (EATS), the Advanced Time-Space-Position Information (ATSPI) system[1], and two Mobile Automated Field Instrumentation System (MAFIS) cases, one with 200 players (the near-term goal), the other with 1000 players. These range systems were selected because they span the numbers of players usually encountered in multi-player evolutions and have different mixes of player types. One tacit assumption made in selecting these particular systems (which are training or tactical and operational testing but not equipment testing systems) is that a data link that can handle the multi-player case will be able to handle the fewer player/more data per player equipment testing case.

3.1 Position and Event Messages

In calculating data rates, it was assumed that player messages would be of two classes: "position" messages and "event" messages. A position message conveys the player's coordinates and

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[1]Although development of this system was terminated, a specification listing players and data requirements was prepared.

velocity at an identified instant, and is sent at a fixed rate specified by the range system for each type of player (Table 3-1).

An event message captures the time at which the player took some action (detected the target, dispensed chaff), and may also contain data needed for evaluation from player systems or test items; for example, a missile fire message might contain attitude, attitude rate, and air mass data as initial conditions for a missile flyout model. However, an event message does not contain position data; rather, it is assumed that position and velocity at the instant of the event are interpolated from the player's position messages that bracket the event in time.

In postulating position and event messages, it was assumed that each player had the requisite sensors to generate the desired data, and that a time- or action-related signal caused these data to be collected, time-tagged, and put on the data link. Details of how this would be accomplished, particularly for operational tactical aircraft, were not considered, although some thoughts on a long-term solution are given in Appendix C. Since the data links were capable of the rates resulting from the generous bit allowances for data elements made initially, no attempt was made to reduce message lengths through the use of sophisticated coding schemes. For the same reason, the messages described below were used for all links, even though some of the header bits might have been duplicated by the data link message structure.

3.1.1 GPS-Derived Position Data

The user equipment specification for GPS Phase IIB equipment[25] describes the operation, interfaces, and outputs for the GPS sets to be developed for 10 categories of host vehicles. Generally, the sets are required to process GPS satellite signals to provide time and three-dimensional position (in any of a large number of coordinate systems) and velocity outputs, and to exchange data

TABLE 3-1

POSITION UPDATE RATES
(messages/second)

Range System/Player Type	Position Update Rate
TACTS	
high interest	20
low interest	.833
EATS	
high dynamic	10
medium dynamic	.625
low dynamic	.313
ATSPI	
fixed wing high interest	5
fixed wing other	1
mobile ground	.500
fixed ground[1]	-
MAFIS	
fixed wing	10
helicopter	6
vehicle	1
troop	.167

[1]These players do not make position reports.

with mission related host vehicle systems (navigation sensors, inertial navigation systems, weapons delivery systems, control and display systems, etc.). All GPS sets provide navigation fixes once per second, and all, except the manpack/vehicular set, have navigation processors that extrapolate position and velocity every 50 milliseconds between fixes.

The Phase IIB sets have an instrumentation port to facilitate collection of data on set operation during developmental testing; ICD-204[26] describes the message formats and contents to be used. One of the functions of the instrumentation port is to provide a GPS-derived time-tag for data routed through it. It was assumed that the instrumentation port and the time-tag function would be retained in operational GPS sets, but that message formats and contents would be streamlined. The message format used in these estimates consists of the following elements:

a. Leader--8 bits

b. Player identification--8 bits

c. Message type/event code--8 bits

d. Time-tag--32 bits

e. Word count (indicates amount of data to follow header)--8 bits

f. Checksum 1 (validates header)--16 bits

g. Data--multiples of 8 bits

h. Checksum 2 (validates the data part of the message)--16 bits.

Three bits (start, parity, and stop) are added to each 8-bit byte by the instrumentation port.

Table 3-2 shows the numbers of bits allowed for various data elements in the position (and event) messages. Bit allowances were

TABLE 3-2

BITS ALLOWED FOR DATA ELEMENTS

Data Element	Bits Allowed	Units
Time-tag		
time of day	27	millisecond
day	5	test day number or truncated Julian date
Position		
x,y	27	1 meter
z	18	1 foot
fix figure of merit	4	BCD index
Velocity*	48	.1 foot/second
Acceleration*	48	.1 foot/second^2
Acceleration rate*	48	.1 foot/second^3
Attitude*	40	.1 degree
Attitude rate*	40	.1 degree/second
Air mass data		
static pressure	16	1.2 millibar
Pitot pressure	16	1.2 millibar
air temperature	16	.5 degree
Vehicle orientation*	48	.1 degree
Gun orientation		
azimuth	13	milliradian
elevation	11	milliradian
Gun orientation rates**	24	.1 milliradian/second

*Three dimensional

**Two dimensional

made in multiples of eight to fit the format above; consequently, some allowances are larger than the estimated requirements. However, it was considered preferable to overestimate rather than underestimate bit needs in this early investigation.

Position message lengths for both air and surface players are given in Table 3-3. In addition to three-dimensional position and velocity, the air player's position message includes three-dimensional acceleration, while the surface player's position message contains two-dimensional position and velocity only.

3.1.2 Event Data

In contrast to position messages, event messages are of variable length. The shortest is the "time-tag" event message which tells only the time at which the event identified in the message occurred. This message requires only the header of the postulated message, containing 80 data bits. Comparison of the kinds of event data required by the various range systems leads to the conclusion that data requirements for pairing and assessment make the "fire" message the longest for each type of player. The air player's fire message provides three-dimensional attitude, attitude rate, acceleration rate, and air mass data; the surface player's provides vehicle orientation, gun azimuth and elevation, and gun azimuth and elevation rates (tank firer as model). The ship player, like the air player, moves in a three-dimensional medium, and hence attitude and attitude rates are required.

The event data just discussed are the kinds that would be used by a central processor to calculate data elements satisfying test or exercise objectives. Besides pairing firer and target and assessing the outcome of an engagement, parameters such as the range at fire, the aspect angle of the target, and target exposure may be of interest. MAFIS will employ a distributed processing system; player instrumentation, which will include a laser pairing device, will

TABLE 3-3

POSITION AND EVENT MESSAGE LENGTHS
(bits)

Player	Position Message	Fire Event Message	Time-Tag Message
Air	352	363	110
Surface	220	264[1]	110

[1]Ship player's fire message same as air player's.

determine the outcomes of engagements between players. Results of the engagement will be conveyed to the central processor, along with the range at fire, target aspect angle, target exposure, etc. To first order, these distributed processing messages are the same lengths as the central processing messages, albeit conveying different data. Hence, the event message lengths of Table 3-3 will be used to estimate data rates for MAFIS as well as for central processor systems.

3.2 Overall Data Rates

As noted above, rates for position updates are specified for each range system. No estimates of the distribution of event message lengths are made, however, and event message rates are estimated only for one range system, MAFIS. In order to proceed, the following assumptions were made:

a. Positions are updated at fixed rates.

b. Events are time-tagged at occurrence.

c. Events are generated at 1 event/sec by 20 percent of the surface and low interest air players.

d. Events are generated at 1 event/sec by 50 percent of the high interest (fixed wing) air players.

e. Event messages from surface players are 75 percent of fire message length, 25 percent of time-tag message length.

f. Event messages from air players are 50 percent of fire message length, 50 percent of time-tag message length.

Assumption c is the estimate used in the MAFIS specification; most MAFIS players are ground units, or helicopters scouting and engaging ground targets. The pace of fixed wing air engagements (both air-to-air and air-to-ground) is faster and was felt to justify a higher event rate (Assumption d). The message length distributions

(Assumptions e and f) are based on message contents for the types of events generated by the various range systems.

Table 3-4 lists the data rates in thousands of bits per second for the five range systems. Event data make up 10 percent or less of the total data to be transmitted.

TABLE 3-4

OVERALL DATA RATES FOR REPRESENTATIVE RANGE SYSTEMS
(k bits/second)

Range System	Data Rate
TACTS[1]	33
EATS	49
ATSFI	73
MAFIS (200 players)	103
MAFIS (1000 players)	513

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[1] Low interest players do not generate events.

4.0 TELEMETRY AS A DATA LINK

One way of providing a data link for GPS data (and perhaps other player data) is to use conventional telemetry. Some form of telemetry is now used by ranges for player event data, or in the case of equipment testing, to obtain periodic readouts of test item parameters. GPS-derived digital data are in principle just another set of parameters to be transmitted on the link.

The question to be asked regarding the use of telemetry is, what bandwidths and data rates would be required if GPS-derived data were to replace that which is currently provided by multilateration systems? Three data capacities are of interest: (a) a dedicated link that would carry GPS set output only; (b) a link that would carry position and state vector data from an inertial navigation system updated by a companion GPS set; and (c) an all data link that would carry both position and event data. The second option should be of practical interest during the transition period for tactical aircraft, when newer aircraft will have internal GPS sets but older aircraft will not. A possible solution would be to provide older aircraft with a pod containing a GPS set, inertial navigation system, and telemetry transmitter; this assumes that the GPS antenna shadowing problem is solved.[27] On the other hand, it would be more efficient to put all player data of interest on a single data link, assuming the interfacing problems can be solved; hence, the third option.

4.1 Assumptions

In estimating the telemetry bandwidths and data rates for the range systems of interest, the following assumptions were made:

a. Time Division Multiple Access (TDMA) is used; the players use GPS system time to synchronize their transmissions.

b. The telemetry frequency will be in either the 1435-1535 or the 2200-2300 MHz band.

c. Propagation guard time for 100 km is included in each time-slot.

4.2 Telemetry Bandwidths and Data Rates for Range Systems

For each range system, the total number of slots per second required to accommodate all player position and event messages was first determined. The bit rate (bits per second) required to transmit the longest message to be sent by any player in a time slot of that length was then calculated, and the telemetry bandwidth in Hz was assumed to be numerically equal to that bit rate.

The numbers of slots for player position reports were derived from the report rates specified for the range systems (Table 3-1); where the specified rates were lower than one per second, players were given alternate use of slots. For example, 18 slots were provided each second for troop position reports for the 200-player MAFIS case; 108 troop players (104 players required), each reporting every six seconds, can use these 18 slots to update their positions at the specified rate. For the third option, the all data link, each player was allotted one slot per second for event reports in the bandwidth calculation.

The message lengths used in these calculations are given in Table 4-1. The message format postulated for the first two options above is modified from that given in Section 3.1.1 by deleting the message type (all messages convey the same type of data), word count (the length of the message is known in advance), and checksum 1 (there will always be a data part of the message; checksum 1 validates the header when that is not the case). The message for the first option contains the three-dimensional position and velocity, requiring 176 data bits or 242 message bits. This message is used for both air and surface players. For the second option, three-dimensional acceleration, attitude, and attitude rate are added to the air players' messages (equivalent for ship players), but the

TABLE 4-1

TELEMETRY MESSAGE LENGTHS
(bits)

Player	GPS Only	GPS and INS	All-Data Position Message	All-Data Fire Message	All-Data Time-Tag Message
Air	242	440	352	363	110
Surface	242	242	220	264	110

ground players, lacking inertial navigation systems, use the 242-bit message. The message lengths for the third option are those of Table 3-3.

Note that while only the longest message was used in calculating the bandwidth required for each range system, the appropriate player position message lengths and the event message rates and length distributions given in Section 3.2 were used in calculating the data rates.

The resulting bandwidths and data rates for the three link options for each range system are shown in Table 4-2. The apparent incongruity in data rates between the second and third options arises because each second-option message from the air players contains attitude and attitude rate (320 information bits total). The third-option air player position message, which generates most of the data to be transmitted, contains only 256 information bits.

A narrowband channel will carry the estimated data except for the second and third options used for the 1000-player MAFIS case. Rather than use a single channel in these two cases, it would probably be more convenient to use separate channels for air and ground players; the corresponding bandwidths and data rates are given in footnotes.

TABLE 4-2

TELEMETRY BANDWIDTHS AND DATA RATES[1]

Range System	GPS only	GPS and INS	All Position and Event Data
TACTS[2]	87 (22)	157 (40)	137 (33)
EATS	30 (29)	55 (53)	69 (49)
ATSPI	49 (46)	89 (82)	125 (73)
MAFIS(200 players)	81 (73)	146 (106)	217 (103)
MAFIS(1000 players)	708 (560)	1290[3] (578)	5060[4] (513)

[1] Bandwidth in kHz--upper figure
(Data rate in k bits/sec)--lower figure

[2] Four players update their positions 20 times/sec, the rest once/sec.

[3] May be divided 962 kHz (559 k bits/sec) for air players, 494 kHz (295 k bit/sec) for ground players.

[4] May be divided 794 kHz (397 k bits/sec) for air players, 538 kHz (117 k bits/sec) for ground players.

5.0 JTIDS AS A DATA LINK

The Joint Tactical Information Distribution System is being developed by a Joint Service program office to provide jam-resistant, secure, digital voice and data links for tactical units. Two versions are being developed: TDMA for the Army and Air Force, and Distributed Time Division Multiple Access (DTDMA) for the Navy. (DTDMA terminals can operate in a mode compatible with TDMA, but not conversely.) TDMA is a message-oriented architecture, DTDMA a channel-oriented architecture; both are very complex, and indeed, are still evolving as equipment and software are developed, making it difficult to pin down the capacity of any JTIDS terminal. Appendix B describes how the terminal capacity estimates (which should be regarded as indicative but not definitive) were calculated for the various range systems.

5.1 Overall Concept

It is assumed that the command and control function in each scenario is performed by players taking part in the evolution; or failing that, that command and control information is presented to the participating players as if that function were being played. This "operational" traffic is estimated to take up less than half of the participating players' terminal capacities; the question is then whether the remaining capacity is sufficient for range data. Although the command and control player may also have excess capacity over operational needs, he may not be located at the range control point; hence, it is assumed that range data requires a dedicated range receiving terminal. It seems likely that if JTIDS were used as a range data link, the range would prefer to have its own terminal(s) to simplify the transition between exercises.

Both versions of JTIDS have a relative navigation function that now uses multilateration of ranging messages sent by users; however, the output is not sufficiently accurate for most range purposes,

even with good geometry. If players have both GPS and JTIDS, it seems certain that they will be connected so that JTIDS can use the GPS-derived position; if this happens, the JTIDS relative navigation position could be as good as the GPS solution, and a separate position message for range purposes might not be required. However, in these estimates it is assumed that the range receiving station does not obtain data from operational traffic.

Both TDMA and DTDMA provide dedicated and reservation access for users. As the names imply, dedicated access provides transmit opportunities to individual users for their exclusive use; reservation access provides a pool of transmit opportunities and a means for each user to request and receive a transmit opportunity from that pool whenever he has a message to send. For these estimates, it is assumed that dedicated access is provided for the periodic position update messages required of players. To conserve capacity, however, the comparatively infrequent event report messages are assumed to be handled by a reservation access scheme.

JTIDS provides two anti-jamming features at the expense of information throughput: Reed-Solomon forward error correction coding and double pulse transmission, both of which would ordinarily be used for operational traffic. Although jamming in the JTIDS frequency band might occur in electronic warfare exercises, a benign electronic environment is assumed, so that neither Reed-Solomon coding nor double pulse transmission are necessary for reception of range data. On the other hand, it would be advantageous to employ either or both if terminal capacity were available, since they would increase the probability that messages will be correctly received. Capacity estimates for both coded and uncoded messages were made, but, with one exception, transmissions were assumed to be single pulse.

5.2 Terminal Capacities

Capacities of the TDMA and DTDMA terminals used in these estimates (see Tables B-1 and B-2) were taken from equipment specifications, but it is not yet clear that all of these specifications will be attained. Two quantities are specified for DTDMA terminals: an average throughput and a peak rate. Average throughputs apply to information bits only (that is, preambles and headers are not included), and are determined by the processing capacity of the terminals. Peak transmission rates include all transmitted pulses and are determined by the heat-dissipation ability of the transmitters, but again are related to processing capacity for the receiver. The transmit and receive capacities of TDMA terminals are given in terms of maximum information throughput; however, a single terminal can only transmit or receive messages in 128 time-slots each second, and this sizes the range receiving station.

The key to the use of players' JTIDS terminals for the range data link is the terminal capacity required for operational traffic. Estimates of this capacity for various terminals are only now being worked out, with final results being classified. One estimate puts the allocation for tactical aircraft at less than 50 percent of DTDMA class II terminal capacity (both transmission and reception),[28] with actual usage estimated at perhaps 60 percent of that.[29] Since the range data requirements for different types of players were estimated at 21 percent of terminal capacity or less (see Tables B-6 and B-7), it was concluded that player terminals could service both operational and range needs.

5.3 Requirements for Terminals at Range Receiving Stations

Table 5-1 shows th estimated capacities required for range data for the various systems, assuming that the players and range receiving station employ the class II TDMA terminal. The packed-2

TABLE 5-1

CAPACITY REQUIRED FOR RANGE DATA:
CLASS II TDMA TERMINAL

Range System	Percent of one Terminal's Average Data Throughput[1]	Number of Nets Required[2]
TACTS	38	2.7
EATS	58	1.2
ATSPI	100	2.0
MAFIS(200 players)	130	2.8
MAFIS(1000 players)	686	13.8

[1] Packed-2 single or double pulse messages for coded data, standard (double pulse) message for uncoded data.

[2] Maximum of 30 nets may be used in one geographic area.

message, either single or double pulse, comes closest to the range data message sizes required when Reed-Solomon coding is used; the standard (double pulse) message without coding is essentially the same size. Since any of the three messages can be sent in one time slot, use of uncoded messages does not reduce the receiving station capacity requirement. Percentages of one terminal's average throughput capacity for all the players for each range system, at the data rates postulated, are given in the second column of Table 5-1. Terminal capacity is obtainable in integral multiples of 100 percent; hence, for example, the 200-player MAFIS case would require two terminals, based on the data throughput condition. However, the governing condition for this application of TDMA is the number of slots required. Player position updates, which constitute over 90 percent of all range data messages, are assumed to be transmitted in dedicated time slots. Since one net has 128 time slots per second and one TDMA terminal can only operate on one net if all 128 slots are used, the number of terminals required is the next highest integral number of nets; the number of nets is given in column three of the table. Since a maximum of 30 nets may be used in one geographic area, the two to three nets required for range data (other than the 1000-player MAFIS case) represent 10 percent of total capacity, leaving what should be an adequate balance for operational uses. Since operational nets would normally be shared by numbers of users employing contention or reservation access, there is probably adequate capacity to provide 14 nets for the 1000-player MAFIS case as well.

Table 5-2 shows corresponding capacity estimates when players have DTDMA terminals, and the range receiving station uses the class I DTDMA terminal. Two differences from the TDMA case may be noted: data throughput is the governing factor, and use of uncoded messages about halves the capacities required. The latter comes about because DTDMA channels can be sized to message lengths if

TABLE 5-2

CAPACITY REQUIRED FOR RANGE DATA:
CLASS I DTDMA TERMINAL, RECEIVE-ONLY[1]
(single pulse transmission)

Range System	Coded	Uncoded
TACTS	29 (56)	17 (34)
EATS	39 (25)	26 (14)
ATSPI	79 (40)	44 (23)
MAFIS(200 players)	86 (55)	48 (32)
MAFIS(1000 players)	429 (275)	142 (102)

[1]Percent of one terminal's average data throughput--upper figure
(Percent of one terminal's maximum reception rate)--lower figure

about because DTDMA channels can be sized to message lengths if fixed-format messages are used.

Table 5-3 shows a summary of the numbers of TDMA and DTDMA terminals required by the range systems. Because the postulated range data messages are short and DTDMA is the more adaptable, the numbers of DTDMA terminals required by the range receiving station are smaller. However, given the necessary equipment, either version of JTIDS seems capable of handling range data for all the range systems.

TABLE 5-3

NUMBER OF JTIDS TERMINALS REQUIRED IN THE RANGE RECEIVING STATION

Range System	TDMA Class II	DTDMA Class I	
		Coded	Uncoded
TACTS	3	1	1
EATS	2	1	1
ATSPI	2	1	1
MAFIS(200 players)	3	1	1
MAFIS(1000 players)	14	5	2

6.0 CONCLUSIONS

Both telemetry and JTIDS appear capable of the data rates estimated for the five range systems considered, if enough resources are provided (bandwidth and terminals, respectively). JTIDS offers an advantage over telemetry in that two optional anti-jamming features (Reed-Solomon coding and double pulse transmission) can be used to increase the probability that messages are received correctly. Perhaps more important, when operational players are equipped with JTIDS terminals, they will be able to use the range without additional data communications equipment.

The number of GPS translators that can be used at one time depends on the frequency allocation that can be obtained. Within the currently defined telemetry bands, allocation for about five C/A code translators appears to be the practical limit.

APPENDIX A

TRANSLATOR FREQUENCY OVERLAP

1.0 INTRODUCTION

The GPS translator receives the superimposed signals from GPS satellites in its view, converts this composite signal to a different frequency, and transmits the signal at that frequency to a receiving station. The receiving station contains a receiver at the retransmittted frequency feeding a GPS receiver that extracts the position, velocity, and time data of the translator at the instant it received the satellite signals.

The translator was developed and first applied to the testing of the Trident missile where space and weight are at a premium and test instrumentation is not recovered at the end of the flight. In addition to being cheaper than a full GPS set, the translator does not require initialization, and there is no problem with acquisition or reacquisition of satellite signals. For SATRACK, the translator output is recorded and combined with monitor station satellite tracking data to produce a highly accurate post-flight missile trajectory.

In a test and training application, real-time or near real-time player positions would probably be required; this, in turn, would probably require a GPS set at the range receiving station for each player. Some receiving station equipment--receiving antenna, pre-amp, computer--might serve all or a number of these GPS sets, but whether or not a cost benefit would be derived by giving each player a GPS set and a data link would require detailed investigation in each case.

Whether the translator is feasible as a source of TSPI data in a multi-player range system depends on the answers to two questions: How far apart must translator center frequencies be, to

identify players; and how close together can frequencies be, to conserve radio frequency (RF) spectrum?

2.0 FREQUENCY SEPARATION FOR PLAYER IDENTIFICATION

To avoid the additional complexity of modulating the superimposed GPS signals at each translator, translator center frequencies must be separated as a means of identifying each individual translator. This minimum separation is determined by the carrier tracking loops of the GPS sets at the receiving station. The frequency ranges over which these loops operate must be too small to allow them to reach the frequencies of the satellite signals from the translators adjacent in frequency. Doppler shifts of 15 kHz at the satellite transmission frequency can be expected for a slow moving player, due to satellite motion; a 600 knot player would have a maximum Doppler shift of about 1.6 kHz. Thus, from the standpoint of carrier tracking, translator frequencies could be separated by perhaps 50 kHz. (Clear acquisition (C/A) codes have been successfully recovered from two equal power L-band signals with center frequencies separated by 30 kHz.)

3.0 FREQUENCY SEPARATION TO CONSERVE SPECTRUM

3.1 Noise Considerations

The incoming signal at a translator or GPS set has been characterized as "noise contaminated by a little signal." The P code signal power is approximately -165 dBW, with a signal-to-noise ratio of about -40 dB; the C/A code signal power is 3 dB higher. Signal powers for all satellites in view are essentially the same, since the satellites are so far away as to be essentially equidistant from the player, regardless of their positions in the sky. Because the satellite signal is so far down in the noise, superposition of signals from the 10 or 11 satellites that may be within view at one time does not materially affect the signal-to-noise ratio for any one of them.

The situation is different at the input to the receiving station of a translator system. Overlaying two translator spectra (center frequencies separated by only enough to maintain carrier tracking on each) results in a 3 dB decrease in signal-to-noise ratio for the satellite signals retransmitted by both translators if both translator signals are received at equal power levels. In a range situation, where the players are not all essentially equidistant from the receiving station antenna, the received powers of translator signals may be quite different because of the dependence of path loss on propagation distance.[1]

Narrowband carrier and code tracking loops make it possible for the spread spectrum GPS set to recover the satellite signals from the noise. If information on player dynamics is available to the set, these loop bandwidths may be made narrower than is the case

[1]It is assumed that the translator is transparent to satellite signals.

when they must accommodate the Doppler shifts. As the noise power increases, tracking loop errors become larger, until a point is reached when the loops can no longer stay locked onto the satellite signal. For an unaided receiver tracking the P code, the signal-to-noise ratio at the carrier loop lock limit is -50 dB. Since the normal signal-to-noise ratio is about -40 dB, the receiver can tolerate only 10 dB of additional noise. Thus, one translator more than three times as far from the receiving station as a second translator whose spectrum it overlaps cannot be tracked. If 10 translators with overlapping spectra are received with equal power, the loops tracking the satellite carriers for each of the 10 players will all be at their lock limits.

Because of its narrower bandwidth and greater transmitted power, the signal-to-noise ratio for the C/A code is about -27 dB. An unaided receiver can thus tolerate 23 dB of additional noise before reaching the carrier loop lock limit. However, the C/A code tracking loop reaches its limit with 18 dB of additional noise.

If inertial aiding can be provided to the GPS set, the loop bandwidths can be decreased, improving noise rejection. Such aiding requires that the translator have a companion inertial set and a data link for transmitting its output to the receiving station.

Table A-1 presents a summary of noise tolerances for carrier and code loops, for both P and C/A codes.

3.2 Estimate of Permissible Overlap

To estimate how close translator center frequencies might be placed, a calculation was made under the following assumptions:

a. The translator output spectrum is as specified for the SATRACK transmitter (3-5) for C/A code; the P code output spectrum was taken to have the same shape but larger bandwidth.

TABLE A-1

CHANGES IN SIGNAL-TO-NOISE RATIOS AT LOOP LOCKING LIMITS[1]
(dB)

Receiver	Code	Carrier Loop	Code Loop
Unaided	P	-10	-16
	C/A	-23	-18
Inertially Aided	P	-19	-27
	C/A	-32	-29

[1]Reference signal-to-noise ratios:
P code -40 dB
C/A code -27 dB

Source: Reference 30.

b. Translator center frequencies are equally spaced, and the frequency of the translator of interest is in the center of a sequence of translators.

c. The noise from the adjacent translators will be spread over the pass band of the translator of interest.

d. The range receiving station's receiver bandpass characteristic is the same as that of the translator's transmitter

e. The translator of interest is a factor of 10 farther from the range receiving station than the translators adjacent in frequency.

To carry out this calculation, curves of noise added by one adjacent translator due to spectral overlap with the translator of interest were constructed for both C/A and P codes. This was done by multiplying the adjacent translator's output power in a 250 kHz frequency interval by the receiver's attenuation in that interval (the product is a function of the center frequency separation) and adding products over the region of overlap. The signal-to-noise ratio for a given translator center frequency separation and code was then calculated by adding noise contributions from translators both higher and lower in frequency to the noise for the translator of interest (which, like that translator's signal, was reduced 20 dB due to the relative distance assumption).

Curves of signal-to-noise ratio as a function of translator center frequency separation for C/A and P codes are shown in Figures A-1 and A-2. Both curves are asymptotic to the negative signal-to-noise ratio axis as the center frequency separation approaches 0; the knee in the P code curve occurs because only the two translators immediately adjacent to the translator of interest contribute noise in the region between 25 MHz and 10 MHz. Figure A-1 shows that a signal-to-noise ratio of -45 dB, the code loop lock limit, will result if C/A code translator center frequencies are separated by 1.8 MHz intervals; the P code carrier loop lock limit is reached with 19.5 MHz spacing (Figure A-2).

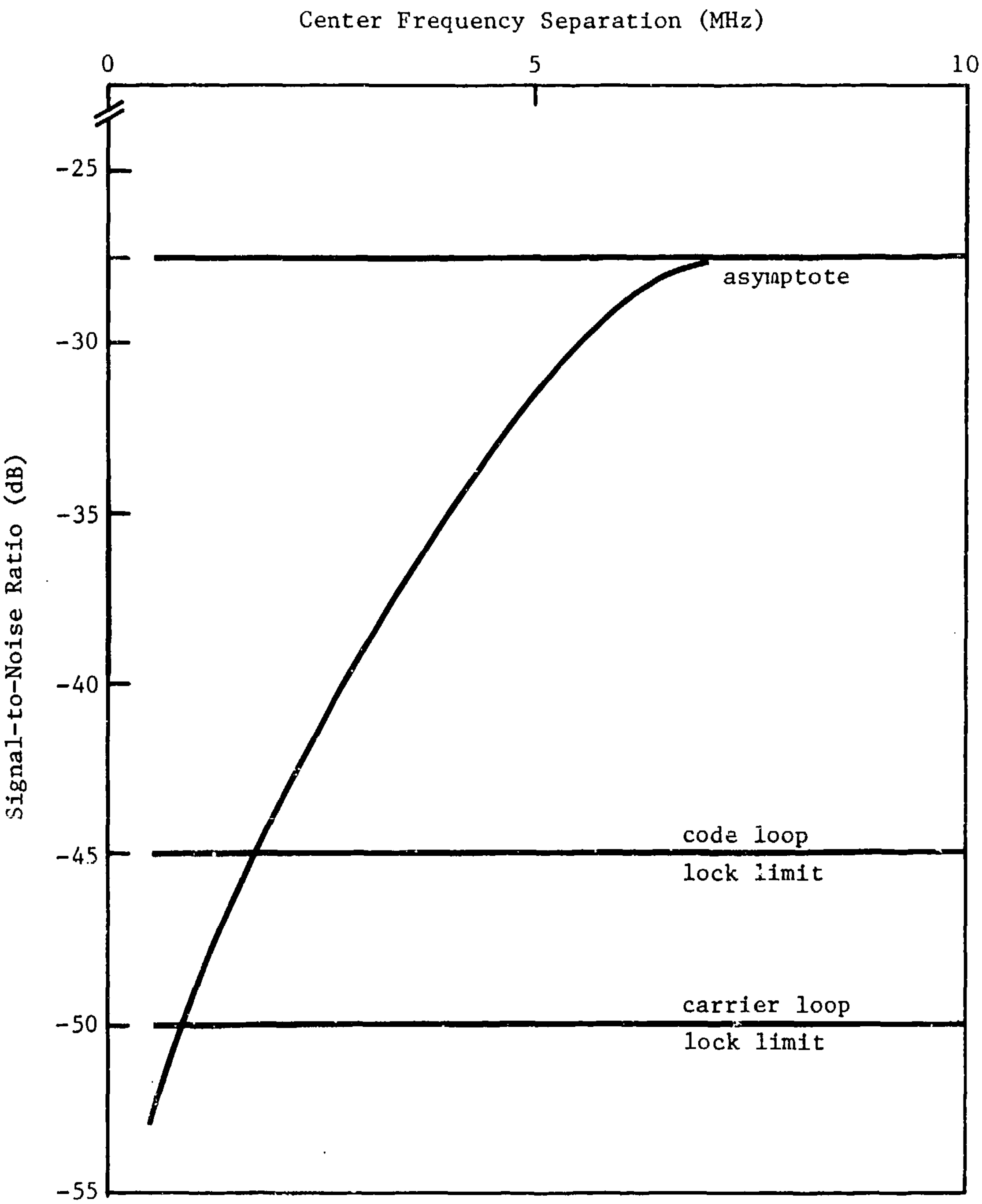

FIGURE A-1
SIGNAL-TO-NOISE RATIO AS A FUNCTION OF CENTER FREQUENCY SEPARATION: C/A CODE, UNAIDED

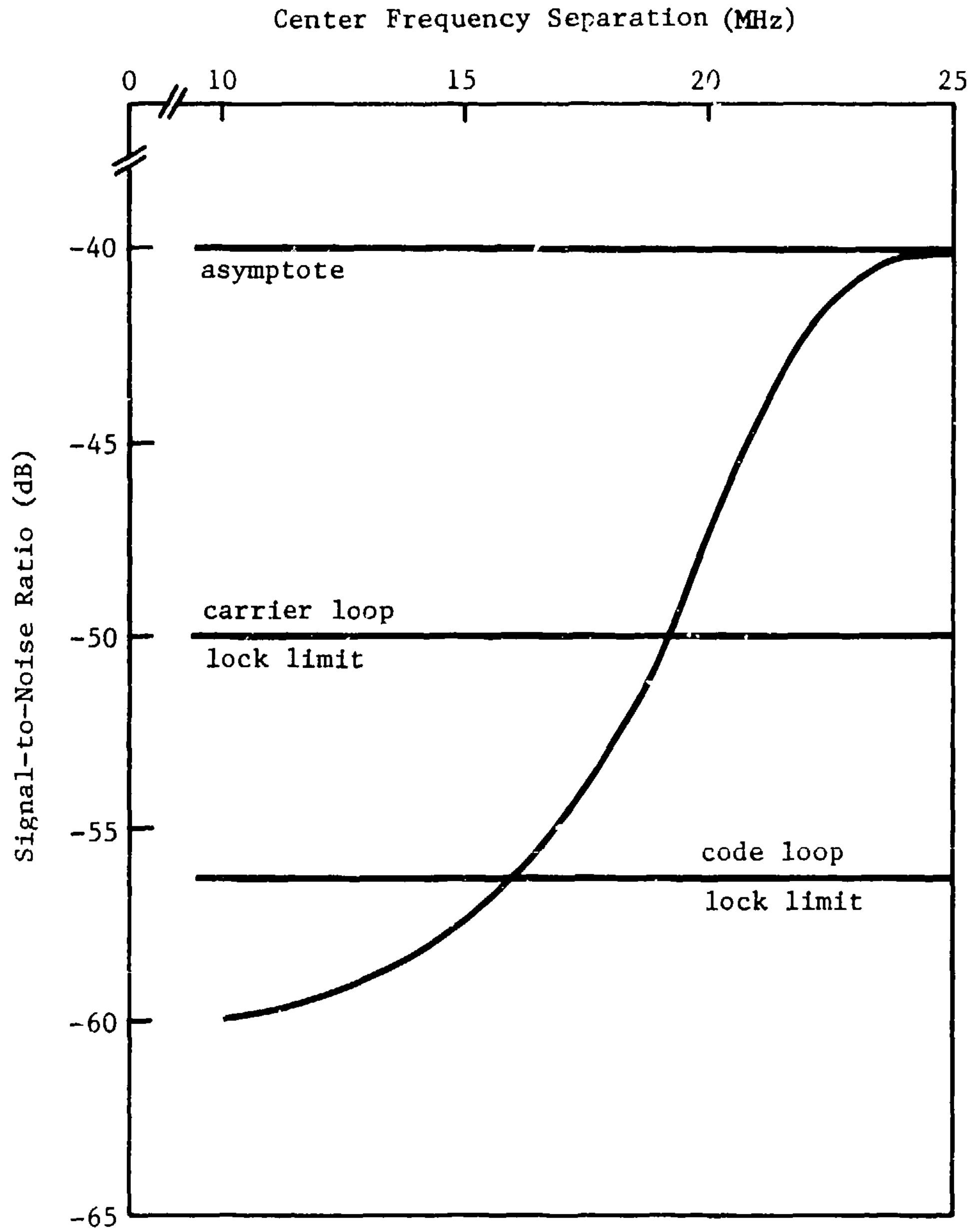

FIGURE A-2
SIGNAL-TO-NOISE RATIO AS A FUNCTION OF CENTER FREQUENCY SEPARATION: P CODE, UNAIDED

4.0 CONCLUSION

Two potentially conflicting requirements affect the separation of translator center frequencies. On the one hand, center frequencies need to be separated to provide a simple way to identify the players; on the other hand, center frequencies need to be as close as possible to conserve rf spectrum in a many-player situation. Center frequency separations of perhaps 50 kHz are enough to prevent carrier tracking loops in the GPS set from locking onto signals from adjacent translators, and hence will satisfy the first requirement. However, as center frequency separations decrease, limiting signal-to-noise ratios are encountered at separations comparable to translator bandwidths for both C/A and P codes, and this condition governs.

The number of translators that can be used at one time thus depends on the frequency allocation that can be obtained. Five P code translators would take up the entire telemetry band, which would probably not be obtainable; in view of other demands for spectrum, allocation for about five C/A code translators appears to be the practical limit.

APPENDIX B
JTIDS TERMINAL CAPACITY ESTIMATES

1.0 INTRODUCTION

The Joint Tactical Information Distribution System is being developed by a Joint Service program office to provide jam-resistant, secure, digital voice and data links for tactical units. Two versions are being developed: TDMA for the Army and Air Force, and DTDMA for the Navy. (DTDMA terminals can operate in a mode compatible with TDMA, but not conversely.) TDMA is a message-oriented architecture, DTDMA a channel-oriented architecture; both are very complex, and indeed, are still evolving as equipment and software are developed, making it difficult to pin down the capacity of any JTIDS terminal. Several specific assumptions were made, and the resulting estimates of terminal capacity may be regarded as indicative but should not be taken as definitive.

It is assumed that the reader is familiar with the basic features of both the TDMA and the DTDMA versions of JTIDS. In this appendix, only those features affecting the capacity calculations will be discussed.

2.0 ASSUMPTIONS

The principle assumptions used in the capacity estimates are as follows:

a. No range data are derived from operational traffic by the range receiving station.

b. Dedicated access is provided for player position reports, reservation access for event reports. However, the overhead associated with requesting and receiving transmission time under the reservation access scheme is ignored.

c. The range is assumed to be electromagnetically benign, so that the Reed-Solomon and double pulse anti-jamming features of JTIDS are optional rather than required. Use of either feature approximately doubles the number of bits that must be transmitted to convey a given number of information bits; use of both features approximately quadruples the number of bits that must be transmitted. Because both features increase the probability that a message will be correctly received, use of either or both would be desirable if capacity is available.

3.0 OVERALL CAPACITIES OF TERMINALS

The terminal capacities appearing in equipment specifications are summarized in Tables B-1 and B-2. These specifications should be regarded as goals at this time, since it is not yet clear that all of them will be attained. Two quantities are specified, an average information throughput and a peak rate.

The average information throughput (information bits per second) is determined by the processing ability of the terminal. The numbers appearing in Table B-1 apply to the data part of the message only; sync bits, preambles, and headers, which are part of every message, are not included. It should be noted that the throughputs for Reed-Solomon coded and uncoded messages differ because the Reed-Solomon code bits are not considered "data." On the other hand, each Reed-Solomon-coded word contains five second-level parity bits to detect situations where the decoder has corrected a word having more than 16 errors, and these five parity bits are considered data. Similarly, the two word-format bits in each TDMA Reed-Solomon-coded word and the 11 label and message-length bits in the first word of the message are considered data. Both parity and word format bits are taken into account in sizing messages for these estimates.

The DTDMA terminal specifications actually contain three average throughputs, one for transmit-only, one for receive-only, and one for both transmit and receive concurrently. On a plot with receive capacity on the ordinate and transmit capacity on the abscissa, three points on a curve are thus given: the intersections with the coordinate axes and one point between. The shape of the curve connecting these points depends on the details of the processor, but it was considered appropriate to go into terminal

TABLE B-1

JTIDS TERMINAL AVERAGE INFORMATION THROUGHPUTS
(k bits/second)

Terminal	Reed-Solomon Coded	Uncoded
TDMA Class II		
transmit	58	120[1]
receive	116	240[2]
DTDMA Class I		
transmit-only	140	280
receive-only	140	280
DTDMA Class II		
transmit-only	40	80
receive-only	70	140

[1]One packed-2 single pulse message in each of 128 time slots/sec.

[2]One packed-4 single pulse message in each of 128 time slots/sec.

Sources: References 32 and 33.

TABLE B-2

JTIDS TERMINAL PEAK RATES

Terminal	Peak Rate
TDMA Class II	128[1]
DTDMA Class I	
transmit-only	1024[2]
receive-only	800[2]
DTDMA Class II	
transmit-only	256[2]
receive-only	400[2]

[1]Time slots/sec.

[2]Data symbols/page (single pulse transmission).

Sources: References 32 and 33.

capacity to this level of detail. Instead, DTDMA terminal capacities were taken to be the transmit-only and receive-only capacities.

The goal for DTDMA transmitters is a 25 per cent duty cycle, resulting in a maximum of 256 pulses (data symbols) per page for the single-transmitter Class II terminal and 1024 pulses per page for the four-transmitter Class I terminal, as shown in Table B-2. All pulses of the message are included, preamble and header bits as well as information and coding bits. Since message overhead is a function of channel mode, it was assumed that DTDMA range data is transmitted on closed channels. These closed channels serve a fixed number of users known to each other in advance, who continually track each other by broadcasting and receiving sync pulses. Such closed channel users are approximately in sync all the time, and the message preamble, which contains a series of sync pulses, can be substantially shortened. The overhead associated with maintaining the closed channel is also ignored.

TDMA is much less flexible. There are 128 slots per second, and one terminal may transmit or receive messages in one of four formats in each time slot. The class II TDMA terminal now being developed can transmit one packed-2 single pulse message in each of the 128 time slots, or a higher data density message in fewer time slots, as long as the average rates shown in Table B-1 are not exceeded. TDMA transmitter and receiver data rates are different because the (newer) receiver was designed to handle a new architecture, while the existing transmitter was retained to avoid the expense of redesign.

4.0 ESTIMATE OF TERMINAL CAPACITIES REQUIRED FOR RANGE DATA

4.1 Range Message Update Rates

Column 2 of Table B-3 lists the player position update rates specified for the range systems considered. These update rates could not be matched exactly with either version of JTIDS because of the way in which message start times are provided.

TDMA time slots are assigned in evenly spaced blocks of 2^N per epoch, where N takes integral values $0 \leq N \leq 15$. Slots for updates were assigned on this basis to yield the update rates given in column 3.

DTDMA message start opportunities occur at 6.554 x 2^N millisecond intervals, where N takes integral values $0 \leq N \leq 9$; that is, every 2^N pages. Column 4 of the table shows the update rates used. One basic event interval per page is the smallest channel capacity that can be assigned.

The event-report rate, nominally one per second, is 1.33 per second for TDMA and 1.19 per second for DTDMA.

4.2 Message Lengths

The basic building block of the JTIDS message data section is a 155-bit (31 data symbol) word. All 155 bits may be information bits; if the message is Reed-Solomon coded, 80 of the 155 bits are Reed-Solomon code bits and another five are second-level parity bits, leaving 70 information bits (57 information bits in the first TDMA word and 68 in succeeding words, as noted earlier).

The shortest TDMA message is the standard (double pulse) message containing three data words, capable of conveying 193 information bits if coded and 465 information bits if not. As shown in column 2 of Table B-4, the longest messages postulated for two classes of players are 363 and 264 information bits, respectively.

TABLE B-3

SPECIFIED AND CLOSEST ATTAINABLE UPDATE RATES FOR PLAYER POSITION REPORTS[1]
(times/second)

Range System	Specified Rate	Closest Attainable Rate	
		DTDMA	TDMA
TACTS			
high interest	20	19.1	21.3
low interest	.833	1.19	.667
EATS			
high dynamic	10	9.54	10.7
medium dynamic	.625	.595	.667
low dynamic	.313	.311	.333
ATSPI			
fixed wing high interest	5	4.77	5.33
fixed wing other	1	1.19	1.33
mobile ground	.500	.595	.667
fixed ground[2]	-	-	-
MAFIS			
fixed wing	10	9.54	10.7
helicopter	6	4.77	5.33
vehicle	1	1.19	1.33
troop	.167	.311	.167

[1] 1.33/sec (TDMA) and 1.19/sec (DTDMA) are used for the nominally 1/sec event report rate.

[2] These players do not make periodic position reports.

TABLE B-4

TDMA MESSAGE LENGTHS

Message Type	Information Bits Needed	Message Structure Coded[1]	Message Structure Uncoded[2]	Information Bits Provided Coded[3]	Information Bits Provided Uncoded
Aircraft position report, fire event; ship fire event	363	packed-2	standard	397	465
Surface player position report; non-ship player fire event	264	packed-2	standard	397	465

[1]Single or double pulse

[2]Double pulse

[3]The data section of the message also includes 53 label, message length, parity, and word format bits.

The standard message is the shortest uncoded TDMA message available. The coded standard message provides only 193 information bits, however, and the next longer message, the packed-2 single pulse with 397 information bits, is required. Note that the terminal must process all of the data bits provided by the message format, whether or not they are used for range data, so that these unused bits count against the capacity.

The corresponding message lengths for DTDMA are given in Table B-5. Two words suffice for the uncoded 264-information-bit message, while six words are required for the coded 363-information-bit message. The message lengths given in the last two columns include information bits, preamble and header bits (preamble E assumed), and Reed-Solomon coding bits for the coded messages. Again, unused information bits count against capacity.

4.3 Estimate of Range Data Requirements

Tables B-6 and B-7 give the estimated percentages of terminal capacity required for range data for TDMA and DTDMA, respectively. The data requirements for individual players were calculated using the position update rates of Table B-3 and the message lengths of Tables B-4 and B-5. To these were added an event message at the nominal rate of one per second, even though players were not assumed to generate events at that rate continually. The requirements for the range receiving station do include events at the postulated rates.

TABLE B-5

DTDMA MESSAGE LENGTHS

Message Type	Information Bits Needed	Information Bits Provided		Message Bits[1]	
		Coded	Uncoded	Coded	Uncoded
Aircraft position, fire event; ship fire event	363	420	465	1105	640
Surface player position; non-ship surface player fire event	264	280	310	795	485

[1]Preamble E assumed

TABLE B-6

CAPACITY REQUIRED FOR RANGE DATA: CLASS II TDMA TERMINAL[1]

Range System	Percent of one Terminal's Average Data Throughput	Number of Nets Required
TACTS		
high interest player	18	.18
low interest player	1	-
range receiving station	38	2.71
EATS		
high dynamic player	9	.09
medium dynamic player	1	-
low dynamic player	1	-
range receiving station	58	1.17
ATSPI		
fixed wing high interest player	5	.05
fixed wing other player	2	-
mobile ground player	2	-
fixed ground player	1	-
range receiving station	100	.01
MAFIS		
fixed wing player	9	.09
helicopter player	5	.05
vehicle player	2	-
troop player	1	-
range receiving station (200 players)	130	2.78
range receiving station (1000 players)	686	13.8

[1]Transmit capacity for individual players, receive capacity for range receiving station.

TABLE B-7

PERCENTAGE OF CAPACITY REQUIRED FOR RANGE DATA: DTDMA TERMINALS

Range System	Player Terminal[1]		Range Receiving Station Terminal[2]	
	Coded	Uncoded	Coded	Uncoded
TACTS				
high interest player	21	12	-	-
low interest player	1	1	-	-
range receiving station	-	-	29 (56)	17 (34)
EATS				
high dynamic player	11	6	-	-
medium dynamic player	2	1	-	-
low dynamic player	2	1	-	-
range receiving station	-	-	39 (25)	26 (14)
ATSPI				
fixed wing high interest player	6	3	-	-
fixed wing other player	2	1	-	-
mobile ground player	1	1	-	-
fixed ground player	1	1	-	-
range receiving station	-	-	79 (40)	44 (23)
MAFIC				
fixed wing player	11	6	-	-
helicopter player	6	4	-	-
vehicle player	2	1	-	-
troop player	1	1	-	-
range receiving station (200 players)	-	-	86 (55)	48 (32)
range receiving station (1000 players)	-	-	429 (275)	142 (102)

[1]Class II, transmit-only

[2]Class I, receive-only
Percent of information throughput capacity--upper figure
(Percent of maximum data symbols/page)--lower figure

APPENDIX C

AVIONICS-BASED TRAINING CONCEPT

Because of the restrictions on modifying operational aircraft (the only kind available in large numbers for testing and the primary users of training facilities), data from air players in tests and instrumented training exercises have often been incomplete. Both the installation of sensors and the transfer of data from sensor to data link transmitter have been problems. The introduction of the MIL-STD-1553 data bus in aircraft provides a potential long-term solution to the second problem, and acceptance by the test and training communities of the data from aircraft tactical systems made available by the data bus would help substantially with the first.

A test application is described in a recent Naval Air Test Center report[34] where aircraft sensors and the 1553 data bus were used in engine accelerated service trials, climatic hanger operations, operational evaluation, and the tactical avionics test program for the F/A-18A. Some care had to be exercised in the calibration and maintenance of production avionics transducers, and some sensors for specialized data had to be added. Substantial savings both in cost (20-36 per cent of the cost of conventional approaches) and time (six hours preparation, rather than six weeks) were realized.

The training application--the avionics-based training concept[35]--has perhaps even greater potential benefits. The goal is to provide operational aircraft with built-in, world-wide training capabilities. The concept's three key elements are the use of GPS for TSPI; the use of internal aircraft systems to generate, and the digital data bus to pass, data; and the use of operational data communications systems (JTIDS) as the data link to the data collection site. The only training-peculiar modification would be

installation of training software in the aircraft computer, perhaps with an operational override.

Training capability as an installed part of operational aircraft would provide greater variety and realism in training scenarios than is possible at fixed training sites, and would make training more readily available at lower organizational levels. Because of its world-wide availability and commonality to all types of players, GPS has a key role in providing this capability.

GLOSSARY

ATSPI	Advanced Time-Space-Position Information
BCD	Binary-coded decimal
C/A	Clear Acquisition
DTDMA	Distributed Time Division Multiple Access
EATS	Extended Area Test System
FAAR	Forward Area Alerting Radar
GPS	Global Positioning System
INS	Inertial Navigation System
JTIDS	Joint Tactical Information Distribution System
kHz	Kilohertz
km	Kilometer
MAFIS	Mobile Automated Field Instrumentation System
MHz	Megahertz
msec	Millisecond
SINCGARS	Single Channel Ground and Airborne Radio System
TACTS	Tactical Aircrew Combat Training System
TASC	The Analytical Sciences Corporation
TDMA	Time Division Multiple Access
TSPI	Time-Space-Position Information

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player location		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Global Positioning System (GPS) is an excellent potential source of time-space-position information (TSPI) for test and training ranges, since this information is available world-wide and can be used by both air and surface players. However, in contrast to ground-based multilateration systems, GPS-derived TSPI is obtained on the player; hence, a means of conveying these data to the range central processor must be provided.

In this report, the feasibility of using existing data communications systems to report GPS-derived player position, velocity, and time data, with and without

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additional player event data, was examined. ta requirements for representative range systems were estimated and matched wi.. the capabilities of representative data links.

It was concluded that telementry and the Joint Tactical Information Distribution Systems (JTIDS) are the most viable link alternatives to convey the GPS-derived data to the range central processor.